

Study on the Effects of Wind Farm on Near-surface Wind Speed of Winter-spring Season

Ronghui Xu^{*1}, Xu Sun¹, Jimei Gao², Jing Liu¹, Xueming Cui¹, Xuehui Cheng², Hongwei Li²

¹College of Ecology and Environmental Science, Inner Mongolia Agricultural University, Huhhot, 010019, Inner Mongolia Autonomous Region, China

²Inner Mongolia autonomous region environment monitoring center, Huhhot, 010019, Inner Mongolia Autonomous Region, China

^{*}xronghui0107@126.com; sunxu507@126.com; ¹ljing58@126.com

Abstract

We chose Zhurihe wind farm, which is located on Sonid Youqi of Inner Mongolia, as our study area. The observation points are set on upwind area, inner wind farm and downwind area, in order to parallelly observe near-surface wind speed within 3m range of wind farm area and discuss the effect of wind farm on near-surface wind speed. The results show that the wind farm consumes wind energy and reduces wind speed of inner wind farm and downwind area. Under the wind speed condition of 1.5-2.5m/s and 8-12m/s, the highest decreasing amplitude of the wind speed at 3.0m height in the wind farm is 22% and 7%, respectively. The wind speed of downwind area are both decrease 5%. The existence of the wind farm has no effect on the form of wind velocity profile, they are all the standard logarithmic curve. Under the two kinds of wind speed conditions, the slope of wind velocity profile inner wind farm decreases 0.3073 and 0.2183. Downwind area decreases 0.0632 and 0.1560. That is to say the fluctuation trend of wind speed increases with the increase of height is not significant.

Keywords

Wind Farm; Wind Speed; Wind Velocity Profile

Introduction

Wind power, as a clean renewable energy, is taken more and more attention of the countries all over the world. However, large-scale construction of wind farms generates economic benefits, at the same time, it also has a certain influence on the local ecological and meteorological environment. Abroad researches on climate impact of wind farm begin in the past ten years, they use model simulation to mainly discuss the changes of meteorological factors at 80-300m height from the surface. D.B.Barrie and D.B.Kirk-Davidoff (2010), Marc Calaf (2011) used the regional climate model to simulate the climatic effect of wind farm,

respectively. Results showed that, atmospheric boundary layer was disturbed by the wind farm, and then surface turbulence and atmospheric water heat flux was increased. As a result, there would be an impact on local climate. Model simulations of SW, Walko RL(2004)、DANIEL B. KIRK-DAVIDOFF(2008), X.Li, S.Zhong and W.E. Heilman (2010), Keith (2004) also obtained the consistent conclusion, wind farm can reduce daily average wind speed at 80m height with seasonal variation. Sten T. Frandsen's (2009) research showed that the difference of the hub before and after the wind farm was gradually significant. When free stream wind speed between 8 and 9m/s, the ratio can be taken as 0.86, 0.88 and 0.93 at about 6000, 8000 and 11,000m behind the leading edge of the farm, and the impact of the wind farm on hub height wind speed was estimated to be noticeable at least 10km downwind. Merete Bruun Christiansen (2005) researched climate change of the large-scale offshore wind farm area. The result was that the average wind speed decreased 8-9% when the wind through the wind farm.

However, weather changes in the high-altitude environment cannot reflect the status of near surface meteorological factors. Near surface meteorological environment changes on arid and semiarid areas, whose ecological environment is relatively fragile, are closely related to grass growth and vegetation construction. Wind farm construction on the ecological impact of these areas is of vital importance, but there are few system researches on impact of wind farms of near surface meteorological factor which are related with water cycle both at home and abroad. This study makes observations within 3m near-surface of wind farm area, and discusses the influence of wind speed

inside and outside of wind farm areas.

Observation Area and Observation Method

The Selection of Observation Area Observation Sites

In order to reduce the influence of terrain factors on wind speed observation, this study chooses ZhuRihe wind farm which is located on Inner Mongolia grassland and has a relatively flat terrain. The study area geographical coordinates for the center position is E 112°47', N 42°31'. The region belongs to arid continental climate, the average temperature is 4.3 °C, the highest and minimum temperature is 38.7 °C and -38.8 °C, respectively. Average annual precipitation and evaporation is 170-19mm and 2384mm. The study area prevails northwest wind throughout the year, the average wind speed is 5.5 m/s and maximum level can reach 9-10. Our study wind farm covers an area of 20 square kilometers with 6km north-south direction and east-west 4 kilometers. The wind farm consists of 33 turbines and each turbine is 65-m-tall with 50-m-long rotor blades.

In study area, we set four observation sites paralleling to the wind direction. Upwind area and downwind area are setted one observation point respectively, and there are two points in wind farm area. The nature of the underlying surface of each observation point is similar. Main soil type is Sandy soil and the main vegetation type is *Stipa breviflora* Griseb. Specific layout of observation points is shown in figure 1.

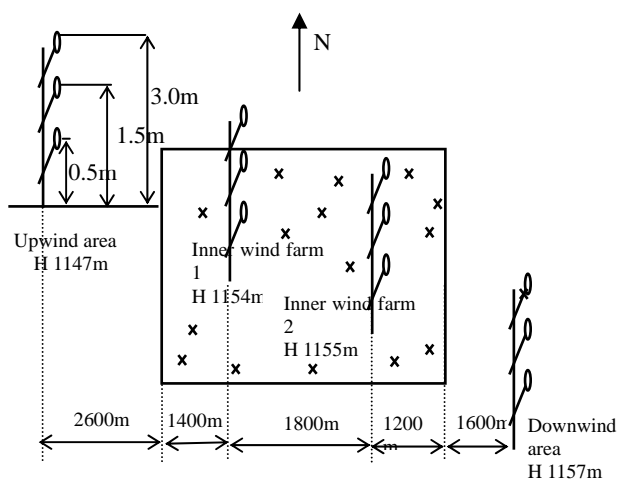


FIG.1 OBSERVATION POINTS

Observation Method

We observe the wind speed of each observation point synchronously. Wind speed value of the height of 0.5m, 1.5m and 3.0m is observed at each point.

The instrument for wind speed observation is HOBO automatic weather stations. Wind speed measurement range and accuracy is 0-45 m/s and ± 1.1 m/s. Start wind speed is 0.5 m/s. Data of the sampling interval is 5min and we take continuous observation from 10:00-16:00 every day. Observing time is from March 24, 2013 to March 28, 2013.

Results and Analysis

The Effects of Wind Farm on Wind Speed

1) The Differences of Wind Speed Inside and Outside of Wind Farm at Low Wind Speed Conditions (1.5-2.5m/s)

Table 1- table 3 is statistics for wind speed at the same height both inside and outside of wind farm. There are 148 groups effective observed data from March 24, 2013 to March 25, 2013.

TABLE 1 WIND SPEED STATISTICS FOR 3.0M OF LOW WIND SPEED CONDITION

observation height	position	wind speed(m/s)			
		0-2	2-4	4-6	6-8
3.0m	upwind area	69	46	27	6
	inner wind farm 1	95	26	24	3
	inner wind farm 2	81	46	21	0
	downwind area	87	51	20	0

TABLE 2 WIND SPEED STATISTICS FOR 1.5M OF LOW WIND SPEED CONDITION

observation height	position	wind speed(m/s)			
		0-2	2-4	4-6	6-8
1.5m	upwind area	81	38	23	5
	inner wind farm 1	95	41	10	2
	inner wind farm 2	95	43	10	0
	downwind area	99	40	9	0

TABLE 3 WIND SPEED STATISTICS FOR 0.5M OF LOW WIND SPEED CONDITION

observation height	position	wind speed(m/s)			
		0-2	2-4	4-6	6-8
0.5m	upwind area	103	41	4	0
	inner wind farm 1	101	42	4	0
	inner wind farm 2	103	42	3	0
	downwind area	101	44	3	0

As we can see from table 1 and table 2, in 1.5-2.5 m/s wind speed condition, distribution regularities of wind speed at the height of 3.0m and 1.5m are the same both inside and outside of the wind farm area. At the height of 3.0m, the number of wind speed data, which distributes within the scope of 0-2m/s, of the two positions in wind farm and downwind area is much greater than the number of upwind area. Wind speed data in the range of 0-2m/s at upwind area, inner wind farm 1, inner wind farm 2 and downwind area accounts for 46.62%, 64.19%, 54.73% and 58.78% of effective observation data, respectively. The wind speed data in the distribution within 4-6m/s of inner wind farm and downwind area is lower than that of upwind area. The wind speed of 1.5m height has similar regularities. Wind speed data in the range of 0-2m/s at four positions accounts for 54.73%, 64.19%, 64.19% and 66.89% of effective observation data. Inner Wind farm and downwind area have no wind speed data within 6-8m/s. Thus, wind farm has an effect on wind speed at the height of 1.5m and 3.0m both in its internal and downwind area. The ratio of wind speed more than 6m/s is dropped, and the occurrences of low wind speed of 0-2m/s increases significantly. In other word, because of wind farm, the wind speed at the height of 3.0m and 1.5m of inner and downwind area decreases. Seen from table 3, in 1.5-2.5m/s wind speed condition, wind speed data at 0.5m height that distributes in the four observation points is balanced. It reflects that wind farm has little influence on wind speed of 0.5m height of its internal and downwind area.

2) The Differences of Wind Speed Inside and Outside of Wind Farm at High Wind Speed Conditions (8-12m/s)

It was windy weather with the gust wind of 6-7 magnitude on March 26, 2013. Minimum wind speed was more than 5.5m/s and maximum wind speed reached 15m/s. Under this weather condition, inside the wind farm, only position 1 observed effective wind speed data.

Figure 2 - figure 4 reflect wind speed variation of high wind speed condition of each measuring points located of different heights. It can be seen from figure 2 and figure 3, the regularities of wind speed at the height of 3.0m and 1.5m are upwind area > downwind area > inner wind farm. The regularity of wind speed at 3.0m height is more obvious, wind speed inner wind farm is much

smaller than the upwind area. Compared with the upwind control, the reduction amplitude of wind speed in wind farm is 3% - 27%, and the reduction amplitude of wind speed in downwind area is 3% - 20%. At the height of 1.5m, wind speed of inner wind farm and downwind area can reduce by 3%-24% and 2.5% -19% respectively, comparing with upwind area. In windy weather with high wind speed condition, the wind speed of inner wind farm at 0.5m height is significantly less than upwind area, the maximum reduction is 25%. The wind speed of downwind area shows a strong instantaneous changes compared with upwind area, there is no obvious regularity, as shown in figure 4.

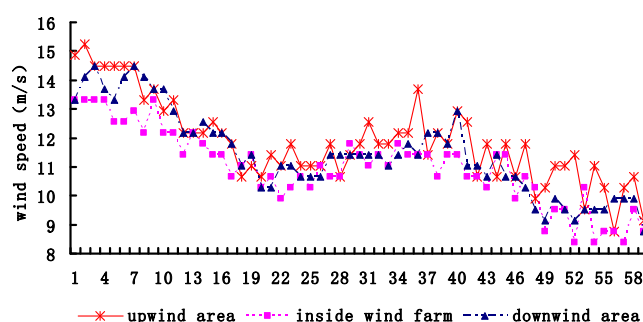


FIG.2 WIND SPEED OF 3.0M HEIGHT OF HIGH WIND SPEED CONDITION

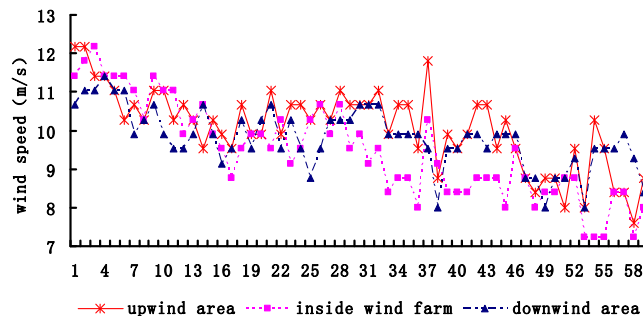


FIG.3 WIND SPEED OF 1.5M HEIGHT OF HIGH WIND SPEED CONDITION

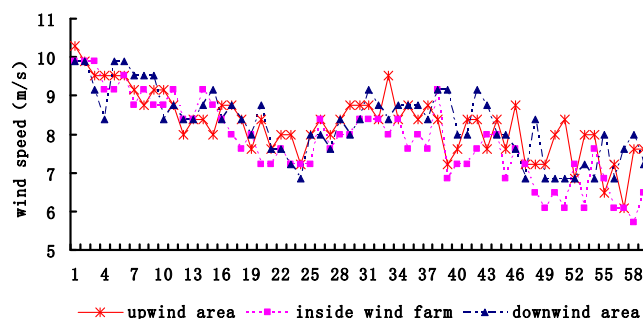


FIG.4 WIND SPEED OF 0.5M HEIGHT OF HIGH WIND SPEED CONDITION

3) Comparison of Average Wind Speed from 10:00 to 16:00.

Because of the randomness of the instantaneous

wind speed is very strong, it is difficult to intuitively reflect the overall variation of wind speed. Average wind speed can reflect overall regularity of wind speed in the area. As a result, the average wind speed during observation period is also analyzed in this paper.

Figure 5 reflects the average wind speed of measuring points of three observation height in different wind conditions. In 1.5-2.5m/s and 8-12m/s two kinds of wind speed levels, the regularity of wind speed of each measuring point at the height at 3.0m and 1.5m is accordant, that is upwind area>downwind area>inner wind farm. And at 0.5m height, under two kinds of wind scale, the average wind speed in wind farm is slightly different.

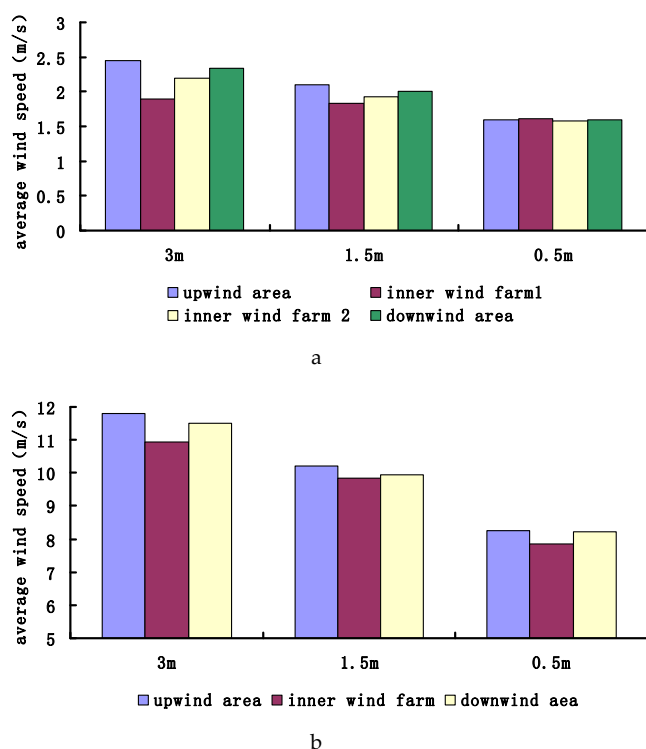


FIG.5 AVERAGE WIND SPEED COMPARISON (A 1.5-2.5M/S WIND SPEED CONDITION B 8-12M/S WIND SPEED CONDITION)

Seen from figure 5a, under 1.5-2.5m/s wind speed condition, the mean wind speed at 3.0m height of two positions in wind farm are 78% and 89% of upwind area, respectively. Wind speed of two points within wind farm decreases obviously, the biggest reduce rate reached 22%. Compared with upwind area, the average wind speed of downwind area reduces 5%. Average wind speed regularity of 1.5m height is similar to 3.0m height. Speed of inner wind farm1, inner wind farm2 and downwind area is 87%, 92% and 95% of the wind speed of upwind

area. The average wind speed of upwind position at 3.0m and 1.5m height is greater than inner wind farm and downwind area. It suggests that wind farm consume wind power and make wind speed loss. Average wind speed decreases obviously. However, the difference of average wind speed at 0.5m height in four observation points is not significant.

Figure 5b shows the average wind speed of each observation point in 8-12m/s wind speed condition. The changes of average wind speed at 3.0m and 1.5m height is similar with the 1.5-2.5 m/s wind speed condition. Wind speed in wind farm decreases obviously, the biggest reduced amplitude is 0.86 m/s, the wind speed decreases 7.3% compared with upwind area. Downwind area wind speed decreases by 3%. Under the condition of 8-12m/s wind speed, the mean wind speed at 0.5m height is no significant difference compared with upwind area.

The Effect of Wind Farm on Near-Surface Wind Velocity Profile

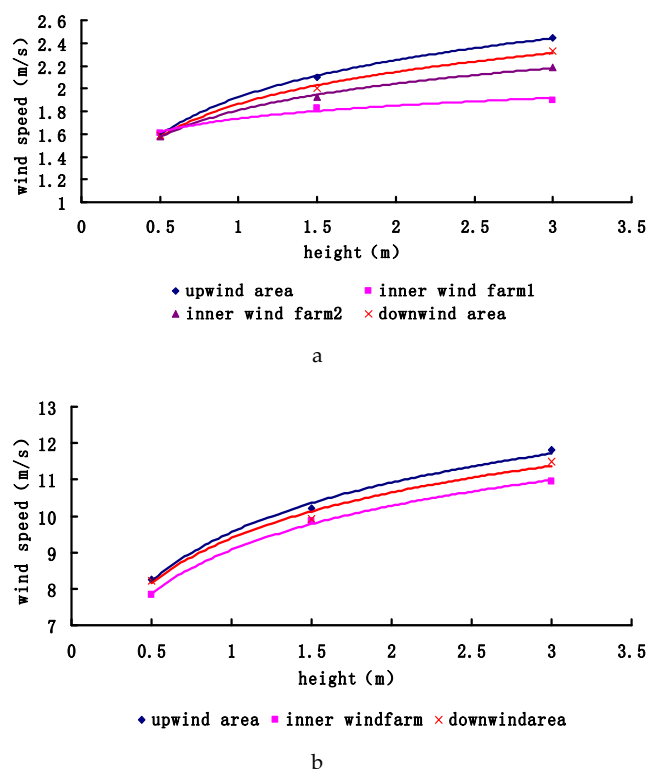


FIG.6 THE WIND VELOCITY PROFILE OF EACH MEASURING POINT IN DIFFERENT WIND SPEED CONDITION (A 1.5-2.5M/S WIND SPEED CONDITION B 8-12M/S WIND SPEED CONDITION)

Wind velocity profile refers to a curve which shows changes in wind speed with height distribution. Under normal circumstances, the wind speed of surface layer

increases with height. Figure 6 shows wind speed profile under two kinds of wind speed condition of each measuring point. We can see from figure 6, under two kinds of wind level, wind speed is increased with the increase of height at the position of upwind area control, inner wind farm and downwind area. The wind speed profile of each measuring point is standard logarithmic curve. The multiple correlation coefficients are greater than 0.95, it shows that the existence of the wind farm does not affect the near-surface wind speed profile form.

TABLE 4 THE REGRESSION MODEL OF WIND VELOCITY PROFILE OF EACH MEASURING POINT IN DIFFERENT WIND SPEED CONDITION

wind scale	measuring points	regression model	correlation coefficient
1.5-2.5m/s	upwind area	$y=0.4726\ln(x)+1.9222$	$R^2 = 0.9992$
	inner wind farm1	$y=0.1653\ln(x)+1.7353$	$R^2 = 0.9745$
	inner wind farm2	$y=0.3385\ln(x)+1.8085$	$R^2 = 0.998$
	downwind area	$y=0.4094\ln(x)+1.8627$	$R^2 = 0.9954$
8-12m/s	upwind area	$y=1.9617\ln(x)+9.5597$	$R^2 = 0.9942$
	inner wind farm1	$y=1.7434\ln(x)+9.0721$	$R^2 = 0.9989$
	downwind area	$y=1.8057\ln(x)+9.3952$	$R^2 = 0.989$

But table 4 reflects that the slope of wind speed profile in wind farm is minimal, compared with upwind area. The slope is 0.1653 and 1.7434 under 1.5-2.5m/s and 8-12m/s wind speed conditions, and it reduces 0.3073 and 0.2183, respectively. The decrease of amplitude of downwind area slope of is smaller, compared with upwind area control, it reduces 0.0632 and 0.1560, respectively. It can be seen that, compared with wind speed changes of upwind area, the vertical distribution of wind speed at the height of 0.5m - 3.0m inner wind farm is relatively homogeneous. Wind speed fluctuations is minimum, wind speed will not occur obvious change trend.

Discuss

This study shows that wind farm can decrease wind speed within the region of 3m from the surface. Results are basically consistent with Robert Vautard(2010), Adams, Amanda S. Keith, D.W.(2007)who studied the impact of wind farm on high-altitude meteorological environmental by using atmospheric circulation model and regional atmospheric modeling system(RAMS).That is to say the existence of wind

farm will affect the local wind speed, the wind speed has a weakening trend after the wind farm. The overall wind goes towards to the small wind, the average wind speed is obviously reduced. Wind speed loss of high-altitude is in the range of 7% to 33%.It Indicates that the existence of wind farm has effect on wind speed for both high-altitude and near-surface meteorological environment. Wind turbines turn wind energy into electrical energy, and at the same time, they also change the atmosphere of the original energy cycle mode. Loss of wind energy is shown as the reduction of wind speed.

However, observational data shows that in the condition of small wind, the influence of wind farm on the wind speed of 0.5m from the surface is not obvious. The wind speed of internal wind farm decreases slightly with the wind speed increases, compared with upwind area. Moreover, model simulation results also show that, at high altitude meteorological environment, the effect of wind farm on downwind area wind speed is more significant than inner wind farm. The wind speed of downwind area decreases obviously. But near surface observation data reflects the wind speed weakened degree of wind speed at downwind area is less than the upwind area.

Conclusion

1) In two kinds of weather conditions that average wind speed is 1.5-2.5 m/s and 8-12 m/s, the regularity of wind speed at 3.0m and 1.5m height is upwind area > downwind area>inner wind farm. Wind speed of internal wind farm decreases obviously. The maximum amplitude of wind speed under the condition of 1.5-2.5 m/s and 8 -12 m/s is 28% and 7.3%, respectively. The wind speed of downwind area reaches more than 95% of the original wind speed of upwind area. Under the condition of the same wind speed, wind farm makes the greatest effect of on wind speed of 3.0 m height. Under the wind speed condition of 1.5-2.5m/s, wind farm's influence on wind speed of inner wind farm and downwind area is more significant than the condition of

8-12m/s.

2) Under the two kinds of wind speed conditions, the wind speed profile of upwind area, inner wind farm and downwind area is standard logarithmic curve .Wind speed of each observation point is increased with the increase of height. But the slope of wind speed profile in wind farm is minimal, compared with upwind area. Reduction amplitude is 65% and

11% under the wind speed condition of 1.5-2.5m/s and 8-12m/s, respectively. Wind speed change of vertical gradient in wind farm is leveling off.

ACKNOWLEDGMENT

This study was supported by National Natural Science Foundation of Inner Mongolia (Grant Nos. 2010ZD16) and Inner Mongolia Agricultural University NDTD 2010-11.

REFERENCES

- Adams, Amanda S. Keith, D.W. "Understanding the impacts of wind farms on climate". *Bulletin of the American Meteorological Society*, 2007, 88(3): 307-309.
- D. B. Barrie and D. B. Kirk-Davidoff. "Weather response to a large wind turbine array". *Atmos. Chem. Phys*, 2010, 10:769-775.
- DANIEL B. KIRK-DAVIDOFF. "On the Climate Impact of Surface Roughness Anomalies". *American Meteorological Society*, 2008, 2215-2234.
- Keith DW, Joseph F, Denkenberger DC, Lenschow "The influence of large-scale wind power on global climate". *Proceedings of the national academy of sciences of the United States of America* 2004; 101(46):16115.
- Marc Calaf. "Large eddy simulation study of scalar transport in fully developed wind-turbine array boundary layers". *PHYSICS OF FLUIDS*, 2011, 23(12).
- Merete Bruun Christiansen, Charlotte B. Hasager. "Wake effects of large offshore wind farms identified from satellite SAR". *Remote Sensing of Environment*, 2005, 98:251-268.
- Robert Vautard, Julien Cattiaux. "Northern Hemisphere atmospheric stilling partly attributed to an increase in surface roughness". *Nature Geoscience*, 2010, 3:756-761.
- Sten T. Frandsen. "The Making of a Second-generation Wind Farm Efficiency Model Complex". *WIND ENERGY*, 2009, 12: 445-458.
- X. Li, S. Zhong W. E. Heilman. "Climate and climate variability of the wind power resources in the Great Lakes region of the United States". *JOURNAL OF GEOPHYSICAL RESEARCH*, 2010, 115.
- Ronghui Xu**, was born in WeiChang, ChengDe city, HeBei province in May, 1987. In 2011, graduated from resources environment and urban-rural planning management specialty of Inner Mongolia agricultural university, Inner Mongolia Autonomous Region, China, received a bachelor's degree of science. In September, 2011, was admitted to soil and water conservation and desertification control major of college of ecology and environmental science, Inner Mongolia Agricultural University, studied for a master's degree.